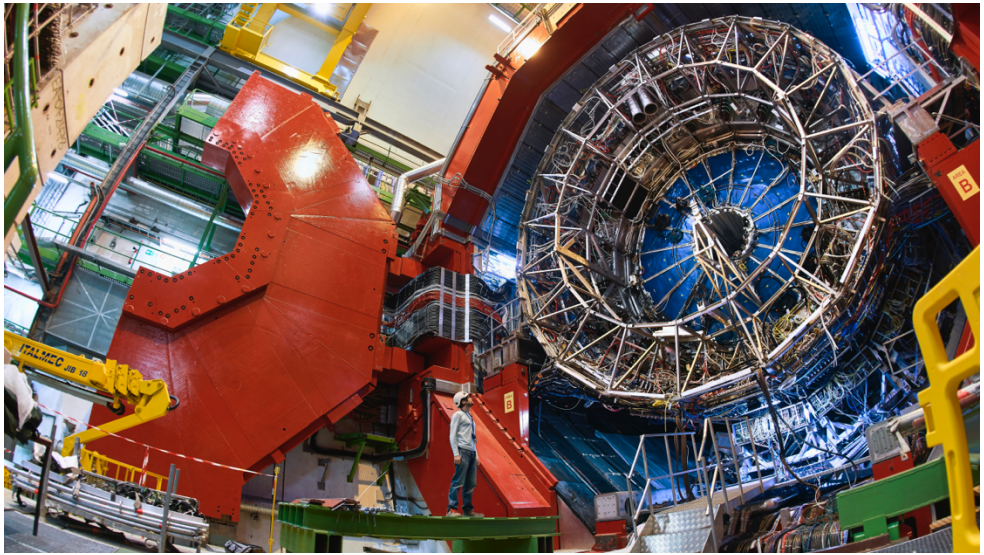
A Large Ion Collider Experiment



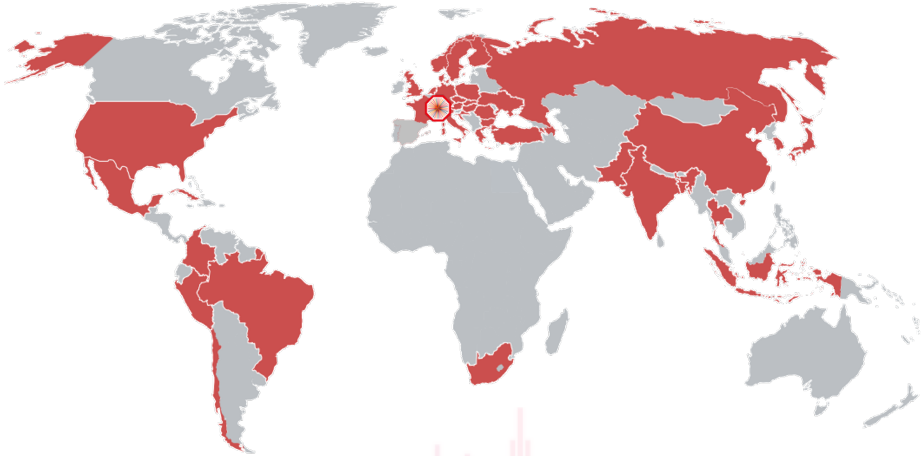
Status report ALICE

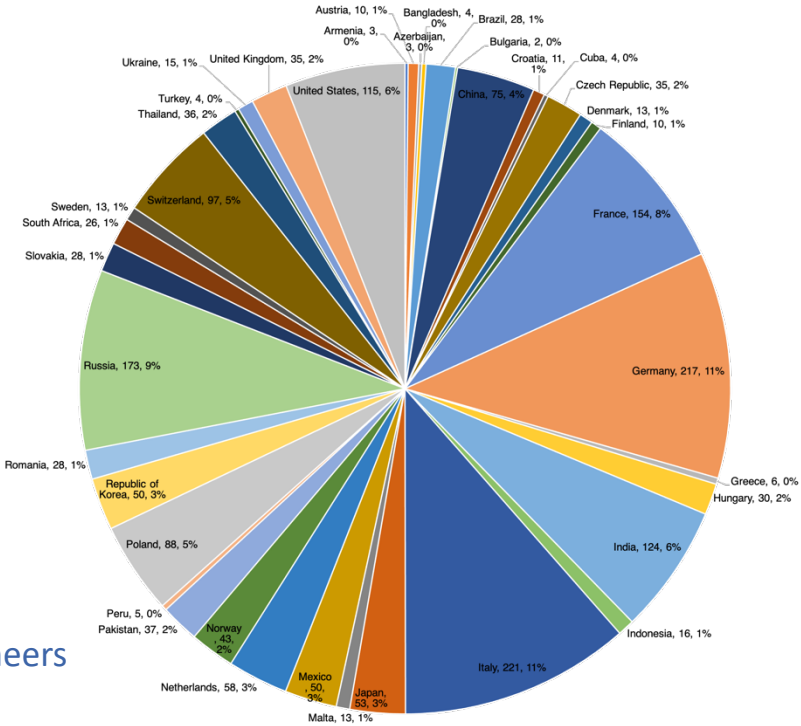
BMBF Forschungsschwerpunkt ErUM-FSP T01

Harald Appelshäuser
Goethe Universität Frankfurt

KHuK Jahrestagung 2020

The ALICE Collaboration





39 Countries, 175 Institutes (including 18 Associates)

1934 Members, about 1000 signing authors

- 941 Physicists (PhD + PhD Students)
- 580 PhD Physicists
- 361 Physics Doctoral Students
- 273 Undergraduate Students
- 49 Senior Engineers
- 225 Engineers
- 11 Technicians

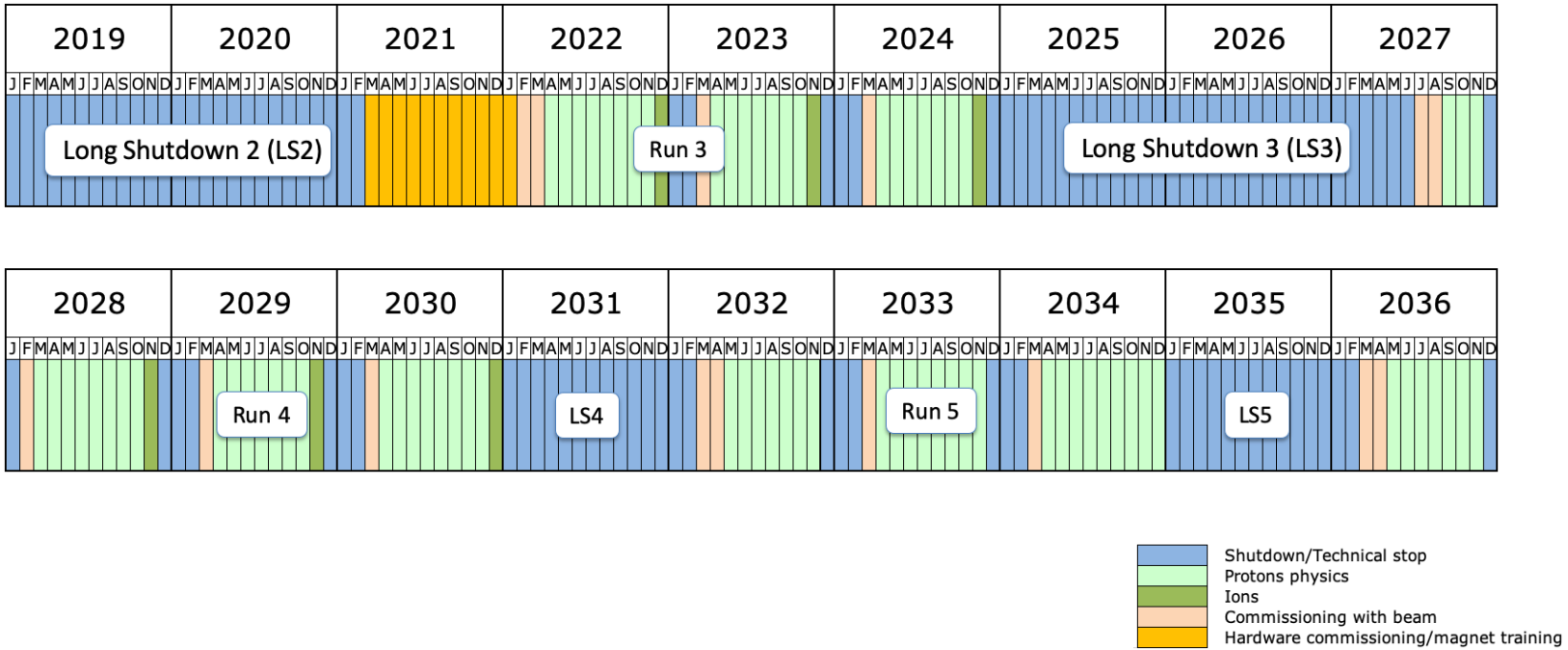
ALICE Germany

Experiment (11 Teams)
- Uni Bonn
- Uni Frankfurt (4)
- Uni Heidelberg
- TU München
- Uni Münster
- Hochschule Worms
- GSI

Theory (6 Teams)
- Uni Bielefeld
- Uni Frankfurt
- TU München
- Uni Regensburg
- Uni Tübingen

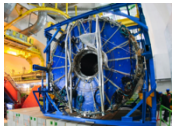
Leading functions of German ALICE members:
- **Collaboration Board Chair:** Silvia Masciocchi (GSI)
- **TRD Project Leader:** Johanna Stachel (Uni Heidelberg)
- **O2-EPN Project Leader:** Volker Lindenstruth (Uni Frankfurt)
- **TPC Project Leader:** Harald Appelshäuser (Uni Frankfurt)
- **Editorial Board Chair:** Yvonne Pachmayer (Uni Heidelberg)
- **Conference Committe Chair:** Dariusz Miskowiec (GSI)
- **Service Work Board Chair:** Kai Schweda (GSI)

ALICE schedule – the big picture

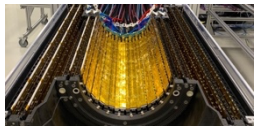


ALICE schedule – LS2 upgrades

GEM TPC

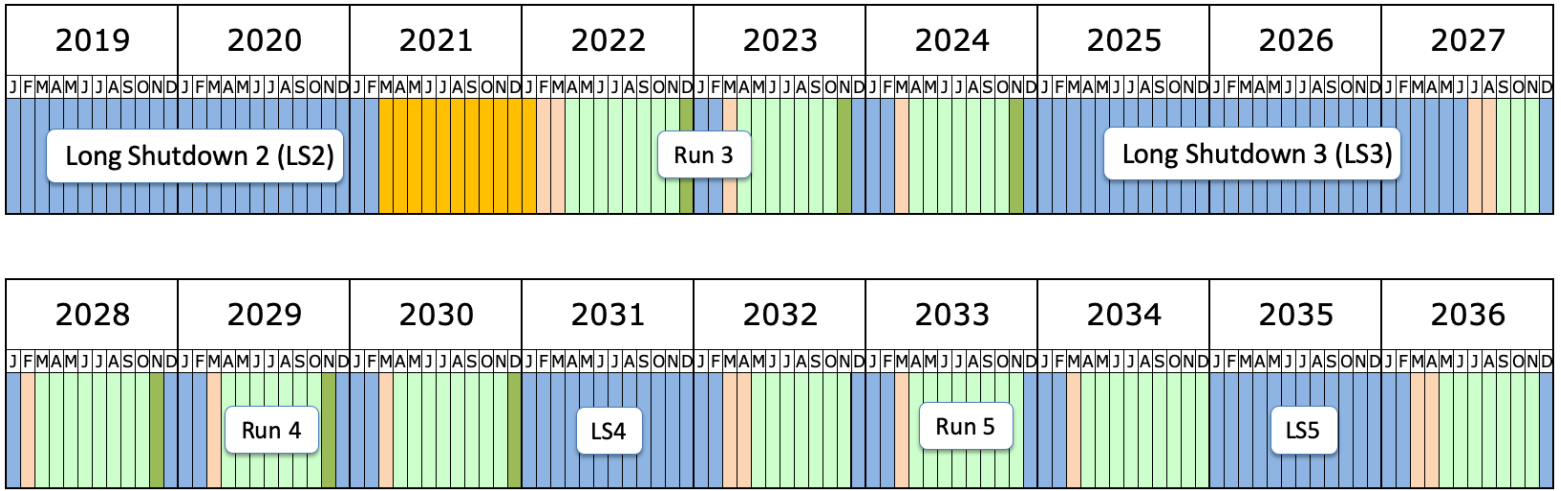


ITS 2



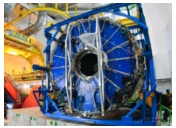
O2

→ factor 50-100 increase in Pb-Pb
factor 100-1000 in pp



ALICE schedule – LS3 upgrades

GEM TPC



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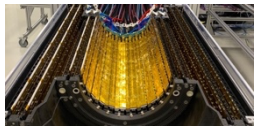
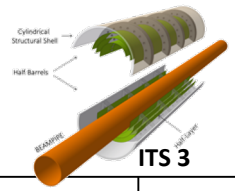
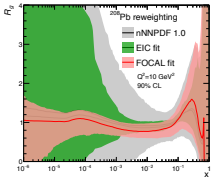


O2

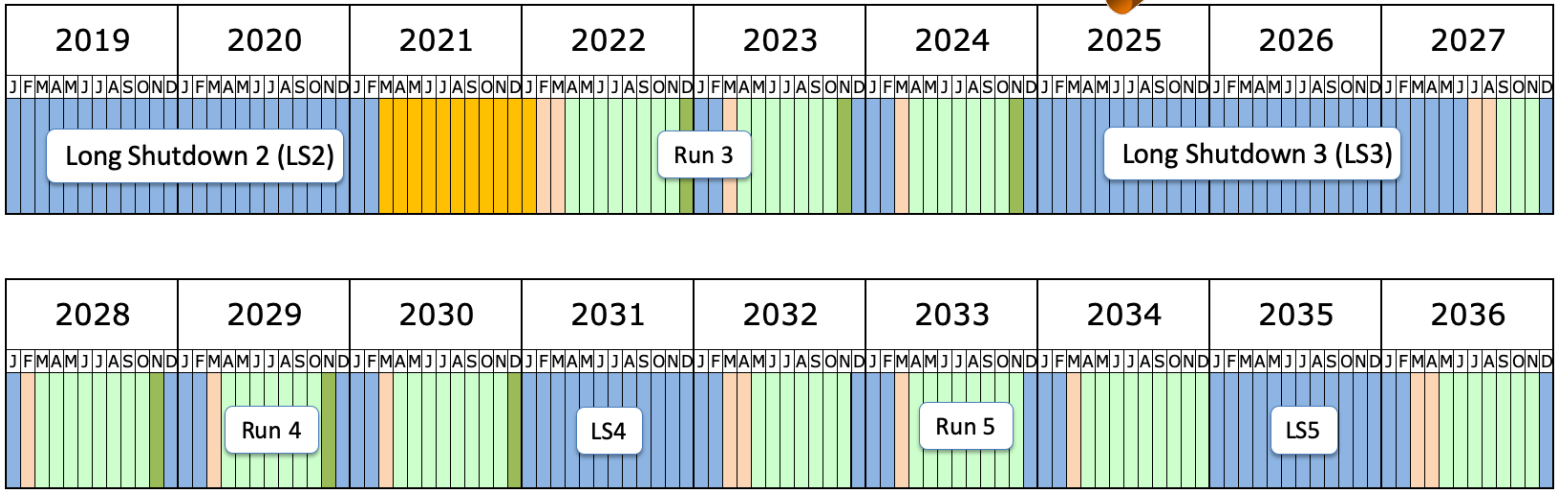
→ factor 50-100 increase in Pb-Pb
factor 100-1000 in pp



ITS 3



FoCal

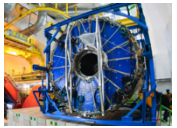


→ improved tracking precision and
forward photon measurement

Shutdown/Technical stop
Protons physics
Ions
Commissioning with beam
Hardware commissioning/magnet training

ALICE schedule – a new experiment: ALICE 3

GEM TPC



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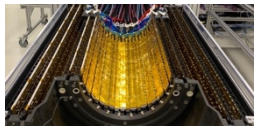
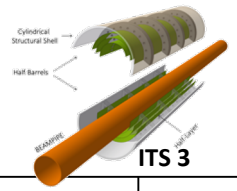
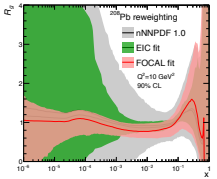


O2

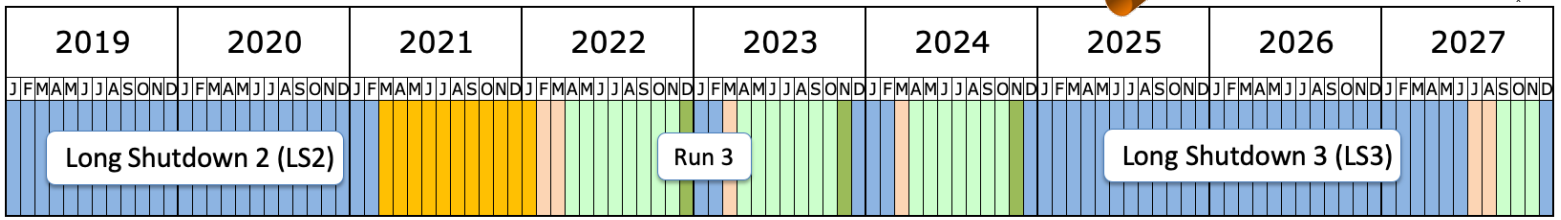
→ factor 50-100 increase in Pb-Pb
factor 100-1000 in pp

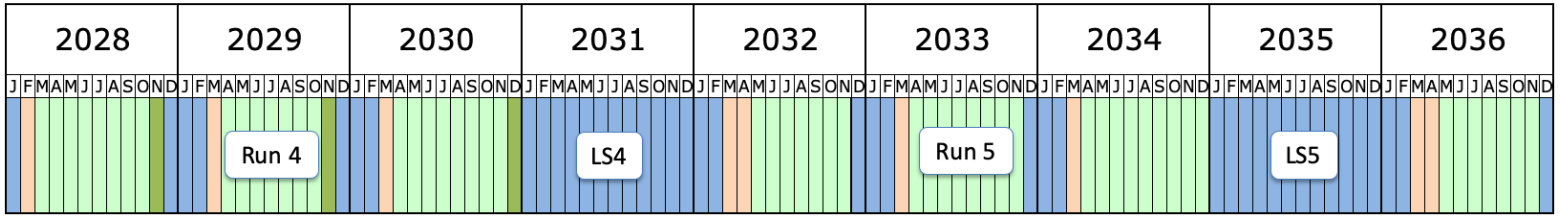


ITS 3

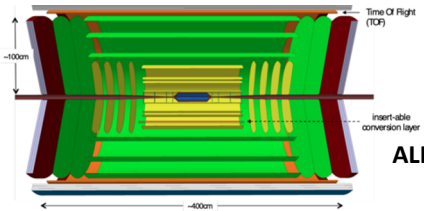


FoCal



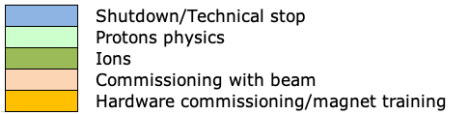


→ improved tracking precision and
forward photon measurement



ALICE 3

→ another factor 50-100 increase in Pb-Pb

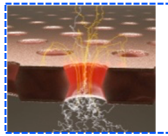


ALICE LS2 upgrades for Run 3 and 4

Goal: **Pb-Pb collisions at 50 kHz, continuous readout**

New Inner Tracking System

- Complementary Metal-Oxide-Semiconductor (CMOS) Monolithic Active Pixel Sensor (MAPS) technology
- Improved resolution, less material, faster readout

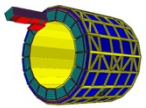


New TPC Readout System

- ROCs with Gas Electron Multiplier (GEM) technology
- New electronics (SAMPA), continuous readout

Integrated Online-Offline System (O^2)

- Record MB Pb-Pb data at 50 kHz
- EPN without trigger



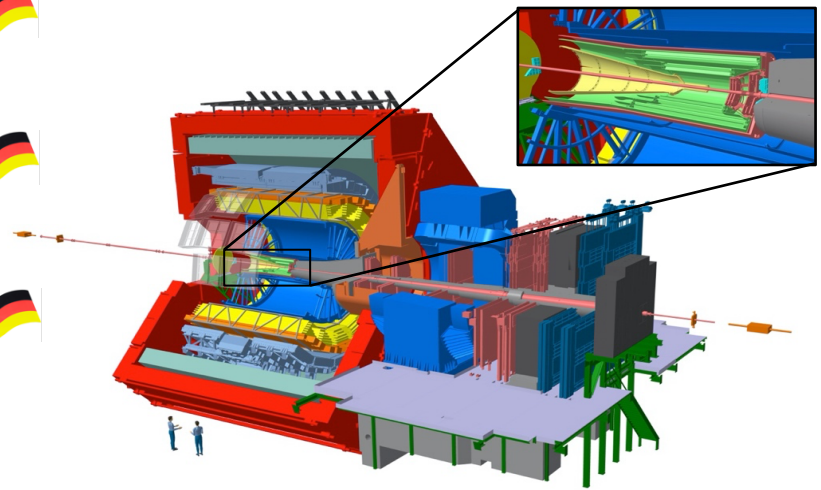
TRD Readout Upgrade and Repair

- Record MB Pb-Pb data at 50 kHz

New Fast Interaction Trigger (FIT) Detector
- Centrality, event plane

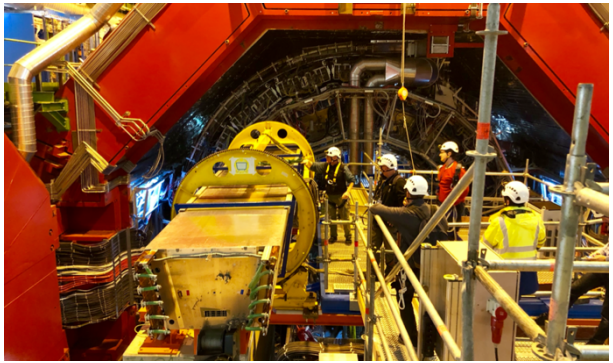
Readout upgrade
- TOF, MUON, ZDC, Calorimeters

New Muon Forward Tracker (MFT)
- CMOS Pixels, MAPS technology
- Vertex tracker at forward rapidity



Run 3 and 4 physics programme: *Z. Citron, et al.*, arXiv:1812.06772
ALICE high-energy pp programme: https://cds.cern.ch/record/2724925

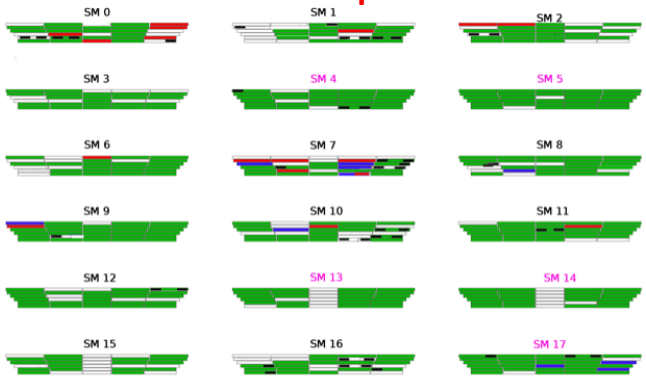
TRD repair and R/O upgrade



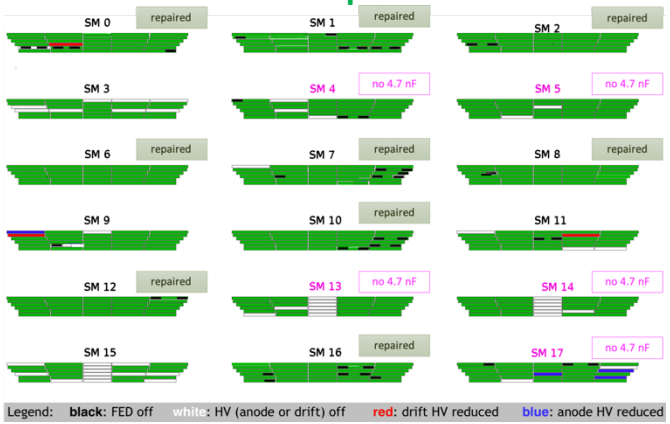
- **HV-stability issues** during operation in Run1/2 due to bad HV capacitors
- 9 (of 18) TRD supermodules **de-installed and repaired** at surface in 2019
- 80 of 83 repaired TRD chambers **fully operational**
- Commissioning of **new TRD readout scheme** for 50 kHz in Run3/4 ongoing

Uni Heidelberg (PL)
Uni Münster
Uni Frankfurt
GSI

Before repair:



After repair:

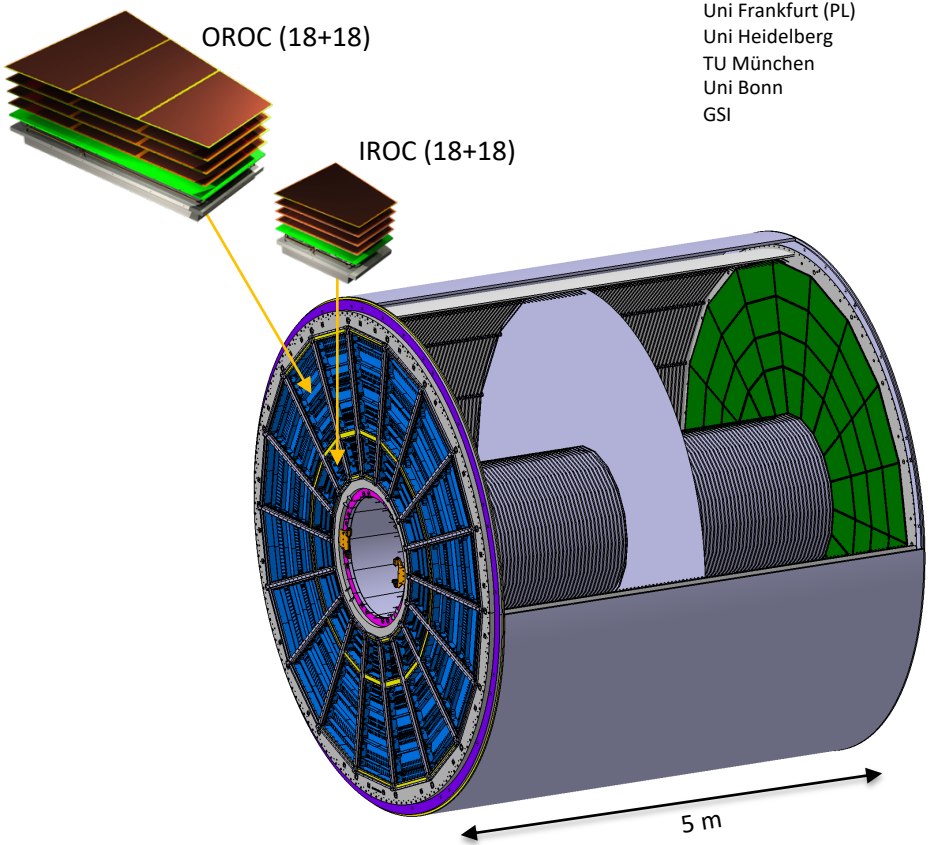


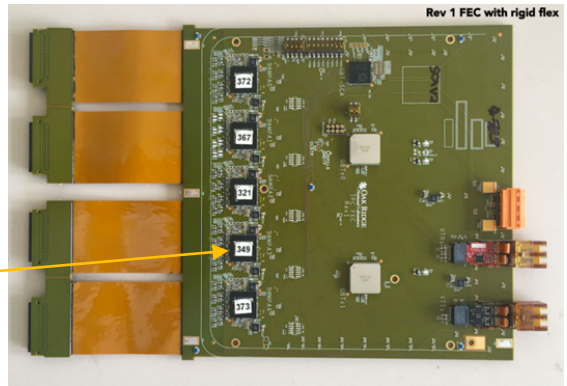
TPC Upgrade

Uni Frankfurt (PL)
Uni Heidelberg
TU München
Uni Bonn
GSI

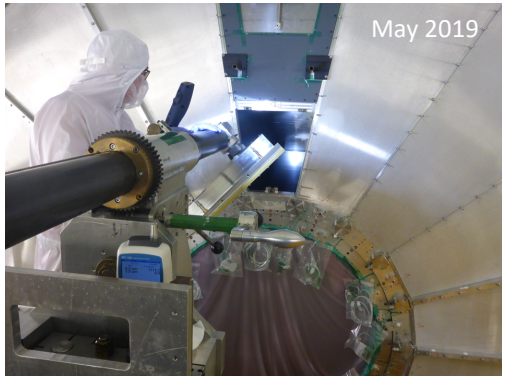
Continuous readout at 50 kHz in Pb-Pb

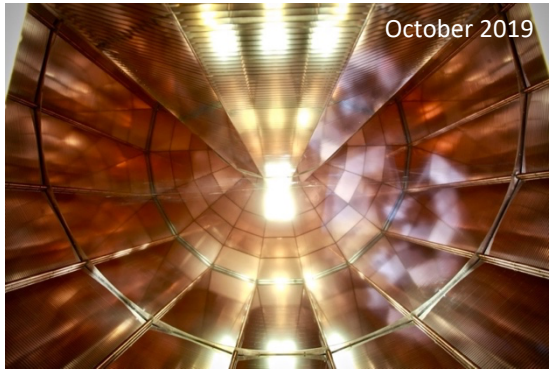
→ **72** new **Readout Chambers** with **GEMs**
→ **3600** new **Frontend Electronics Cards**

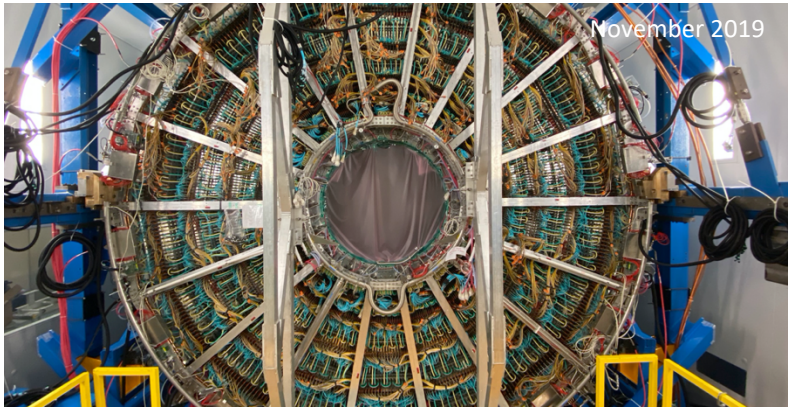




ROC and FEC installation



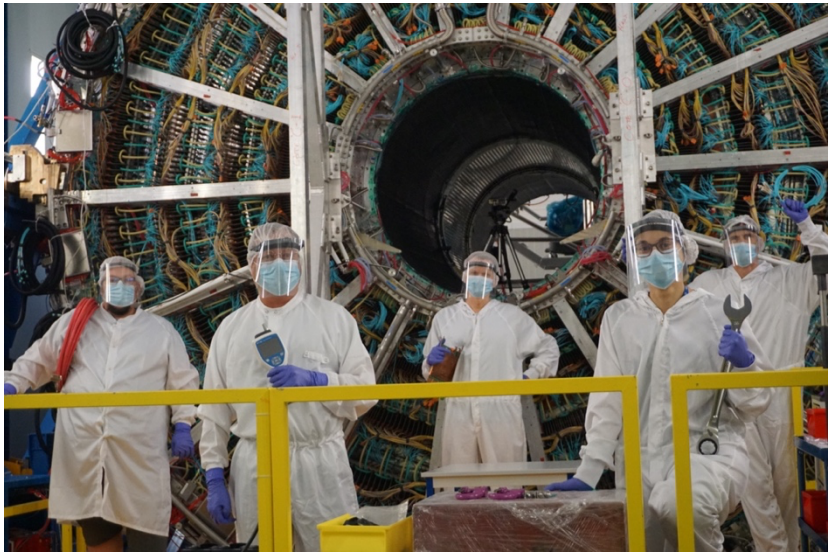




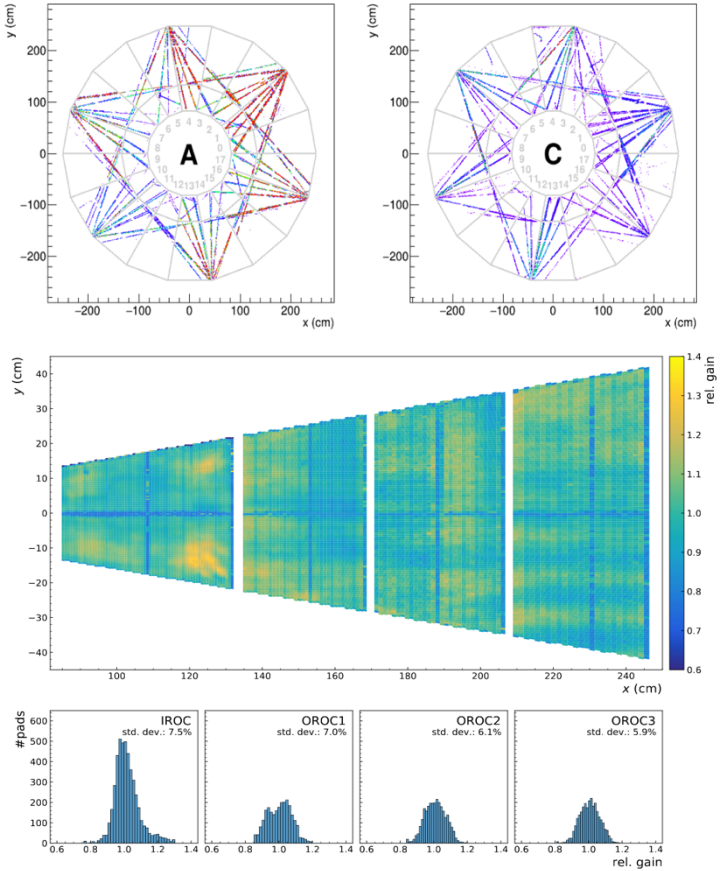
March 2019 – March 2020:

- TPC moved to **surface cleanroom**
- old MWPC readout chambers **replaced by new GEM detectors**
- new **readout electronics** mounted and tested
- **CERN COVID-19 shutdown** March 10, 2020, 3 weeks before planned start of installation in cavern

TPC pre-commissioning



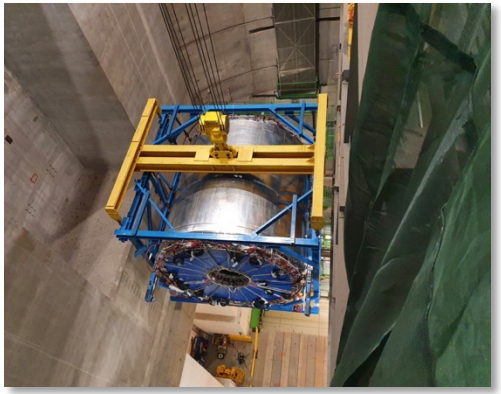
Left to right: R. Münzer (Uni F), C. Garabatos (GSI), L. Bratrud (Uni F), Y. Chatzidaki (Uni HD), C. Lippmann (GSI)

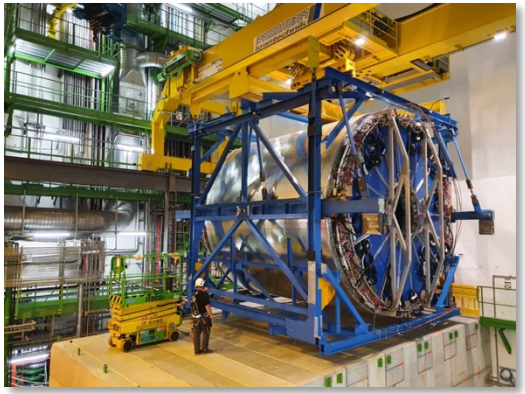


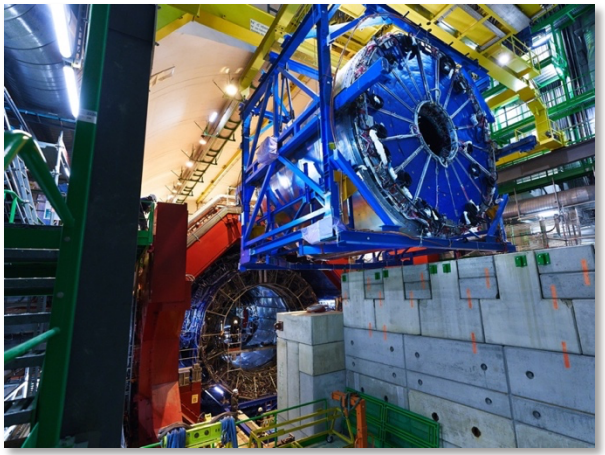
May 2020 – July 2020:

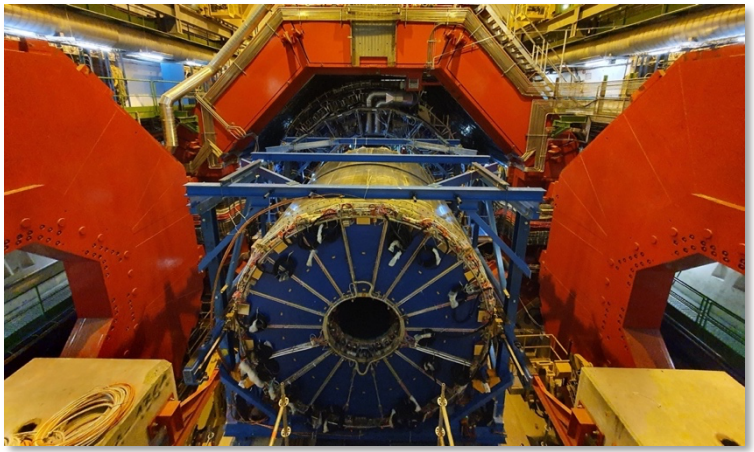
- Full functionality confirmed in **extended irradiation tests** with cosmics, laser, X-rays

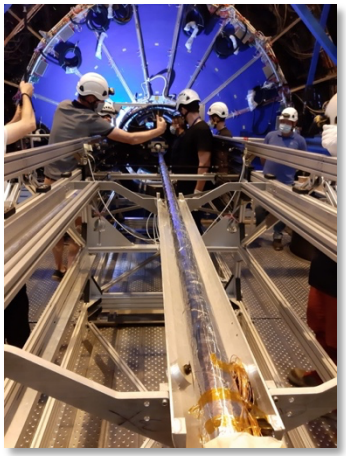
TPC reinstallation in the ALICE cavern (August 2020)



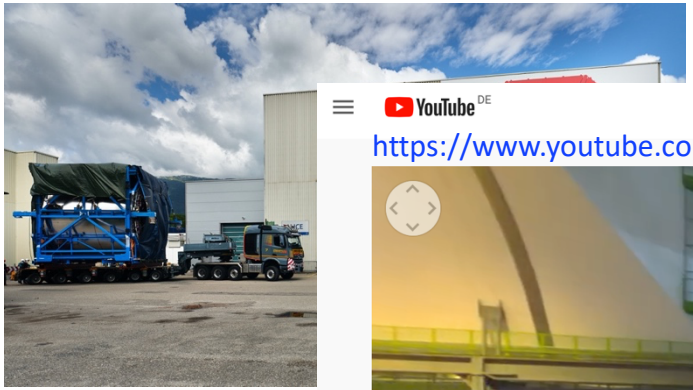


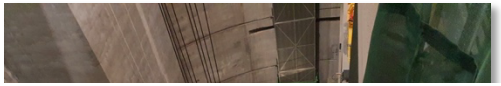


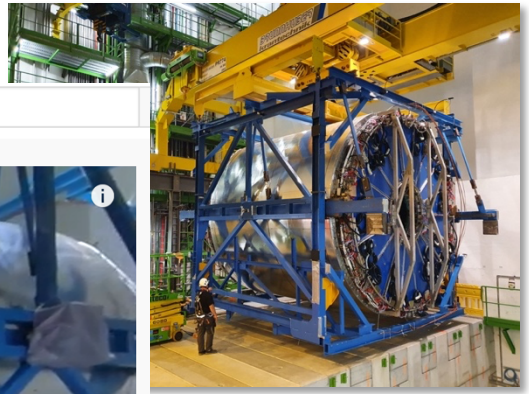


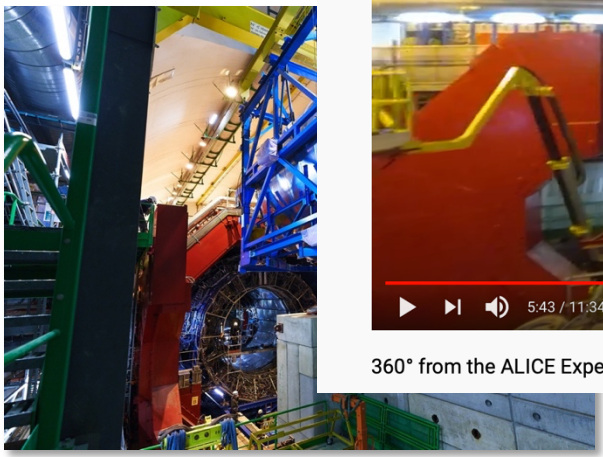


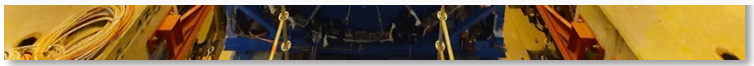
TPC reinstallation in the ALICE cavern (August 2020)

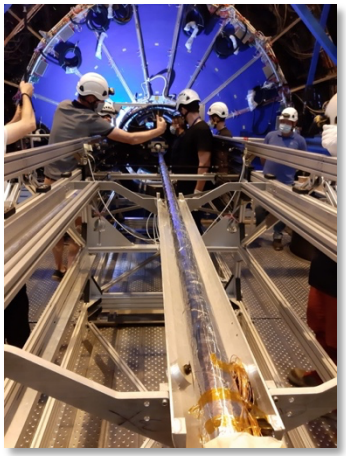








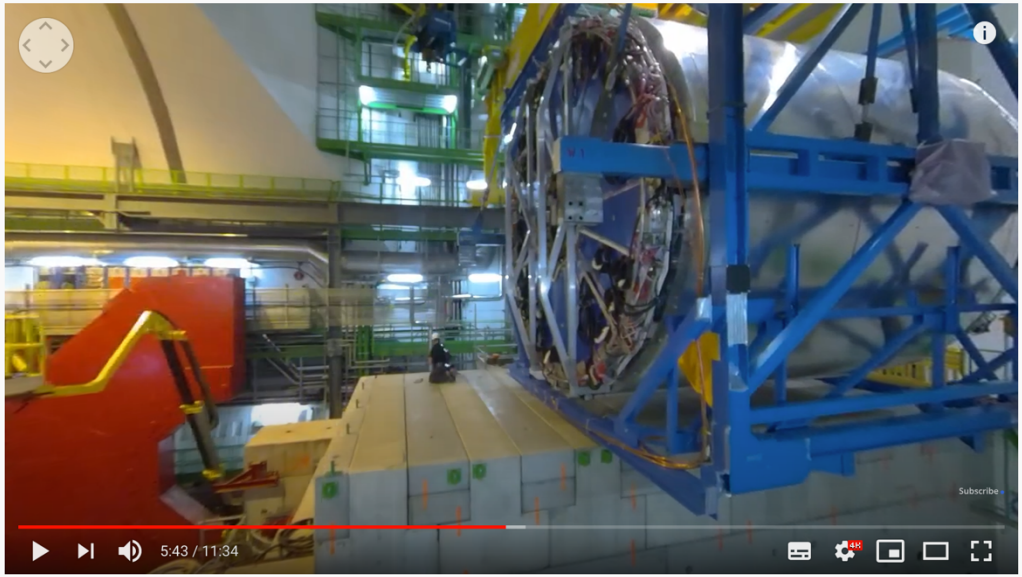




YouTube DE

Suchen

https://www.youtube.com/watch?v=xvhVYrp9hqQ



360° from the ALICE Experiment at CERN - 8K

O2 Event Processing Nodes

- **EPN computing farm for synchronous event reconstruction at O(1TB/s)**
- container-based computing center (CR0)
- 250 servers with 64 CPU cores and 8 GPUs each
- 100 Gb/s InfiniBand Core Network

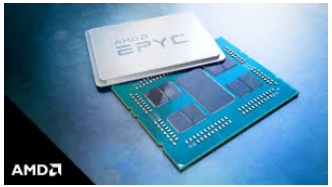
Uni Frankfurt (PL)

→ first servers at CERN end of 2020, full amount Q1 2021

EPN server (1/250)

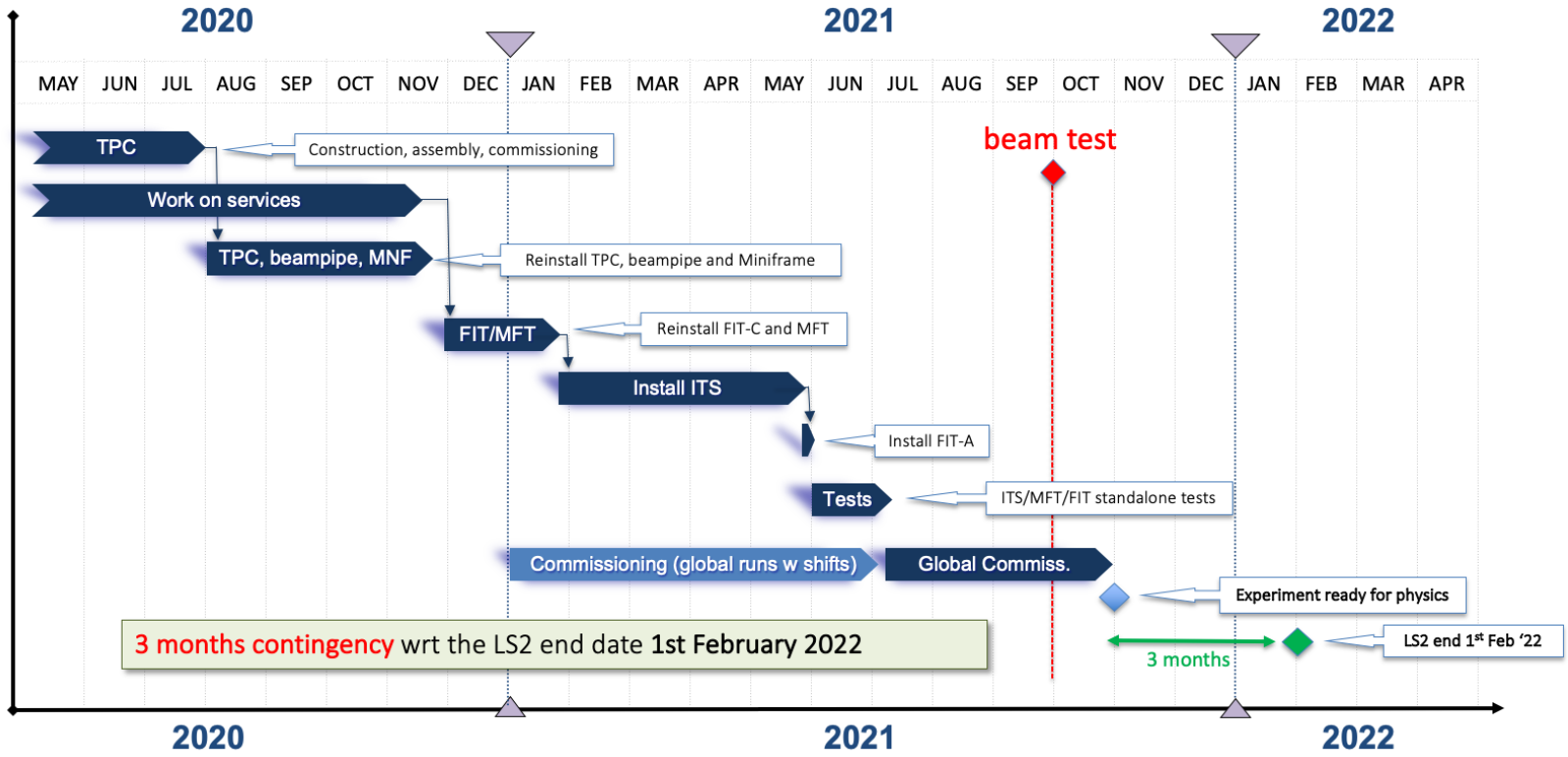
CR0 EPN computing center at Point 2

Multi-core CPU

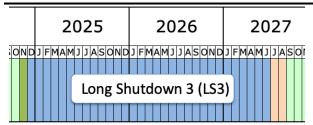


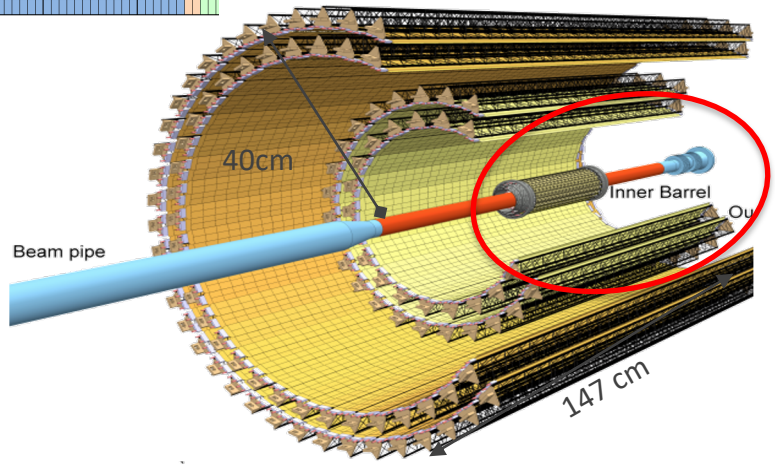
GPU

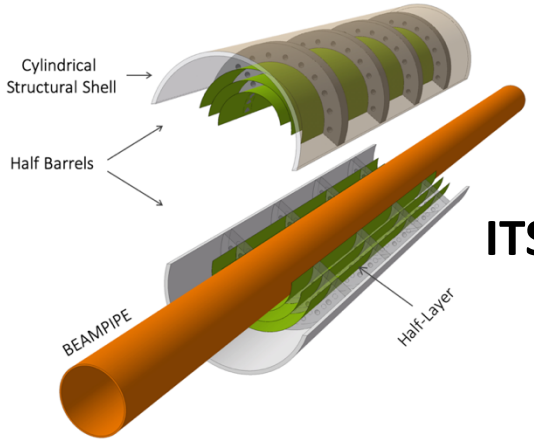
The ALICE Collaboration



LS3 upgrade – Ultra-thin Inner Barrel for Run 4



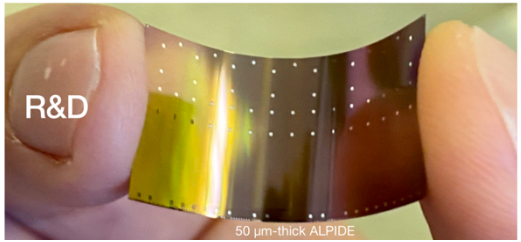




ITS 3

3 *cylindrical layers* of ~7x14 cm² CMOS MAPS, 20-40 µm

- readout outside acceptance
- no water cooling, minimal support structures
- total radiation length: *R* < 4 cm: 1.3% (ITS2) ⟶ **0.3 % (ITS3)**



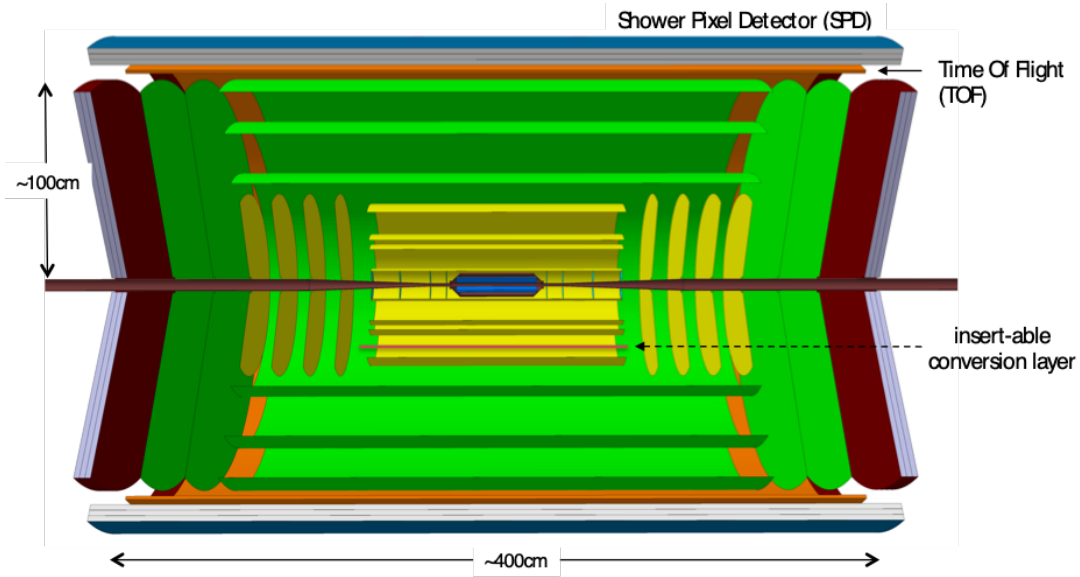
→ R&D contributions from **German groups** in view of **future applications**

ALICE 3: A next-generation heavy-ion experiment at the LHC

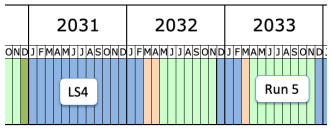
A thin, light, fast, all-silicon tracking and PID detector

Input for EPPSU Process : arXiv:1902.01211

Included in Physics Briefing Book: arXiv:1910.11775



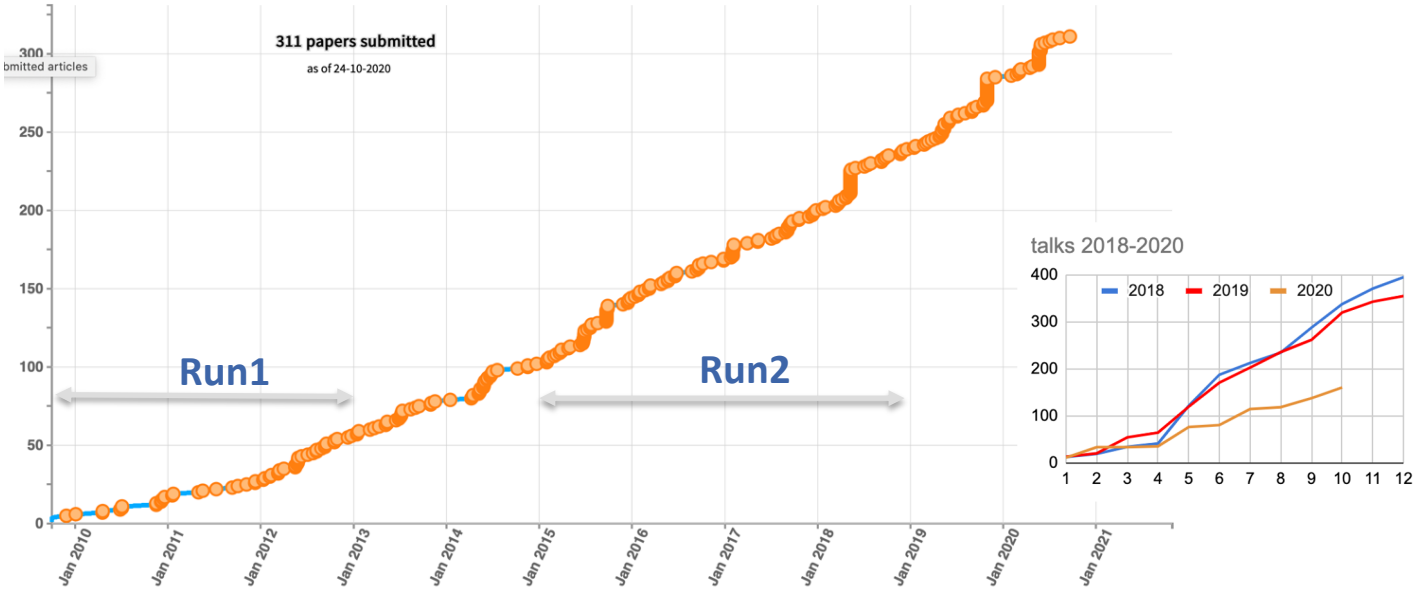
- Multiply heavy-flavored hadrons: Ξ_{cc}, Ω_{cc}, Ω_{ccc}
- $X_{c1,2}$ states
- X,Y,Z charmonium-like states (e.g. X(3872))
- Light exotic nuclei with charmed baryons and multiple hyperons up to A=6
- Thermal EM radiation
- Chiral symmetry restoration
- Soft theorems



- **Letter of Intent** in preparation for end of 2021
- Possible operation starting in **Run 5**
- **German teams** aim for significant contributions:
  - R&D for **ultra-thin CMOS MAPS**
  - forward **soft-photon spectrometer**

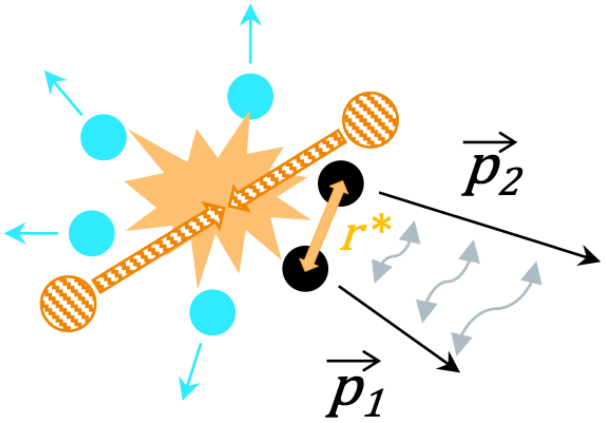
Physics output

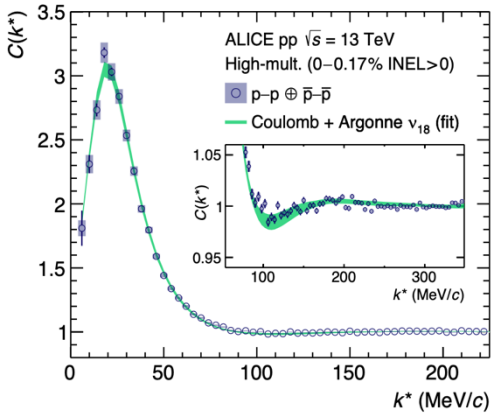
- 311 papers on arXiv
- 36 in 2020



http://alice-publications.web.cern.ch/submitted

Physics highlights: strong interaction among hadrons





- Strong interaction between hadrons accessible via **momentum correlations** in the final state
- LHC is a **factory for unstable hadrons**
- ALICE has **excellent reconstruction and PID capabilities** at low p_T

→ New experimental program developed for **precision measurements of hadronic interactions**

→ Special focus on **hyperons**

p–p, p–Λ, and Λ–Λ correlations studied via femtoscopy in pp reactions at √s=7 TeV
ALICE coll., PRC 99, 024001 (2019)

Study of the Λ–Λ interaction with femtoscopy correlations in pp and p-Pb collisions at the LHC
ALICE coll., PLB 797 (2019) 134822

First observation of an attractive interaction between a proton and a cascade baryon
ALICE coll., PRL 123 (2019), 112002

Scattering studies with low-energy kaon-proton femtoscopy in proton-proton collisions at the LHC
ALICE coll., PRL 124 (2020) 09230

Investigation of the p-Σ^0 interactions via femtoscopy in pp collisions
ALICE coll., PLB 805 (2020) 35419

Search for a common baryon source in high-multiplicity pp collisions at the LHC
ALICE coll., PLB 811 (2020) 135849

Physics highlights: strong interaction among hadrons

- Latest results: **precise measurement of strong interaction between p-Ξ⁻ and p-Ω⁻**
  - direct comparison to **lattice QCD**
  - important for neutron star EoS

- Perspectives for **Run 3:**
  - Ξ-Λ, Ξ-Σ
  - d-Λ, p-Σ, Ω–Ω
  - charm sector
  - Y-N-N interactions

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Article | Published: 09 December 2020

Unveiling the strong interaction among hadrons at the LHC

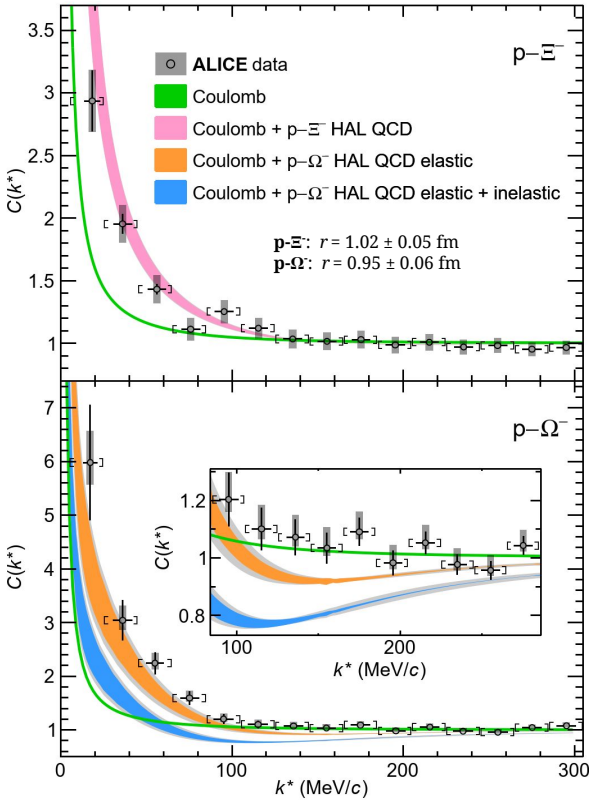
ALICE Collaboration

Nature **588**, 232–238(2020) | Cite this article

Metrics

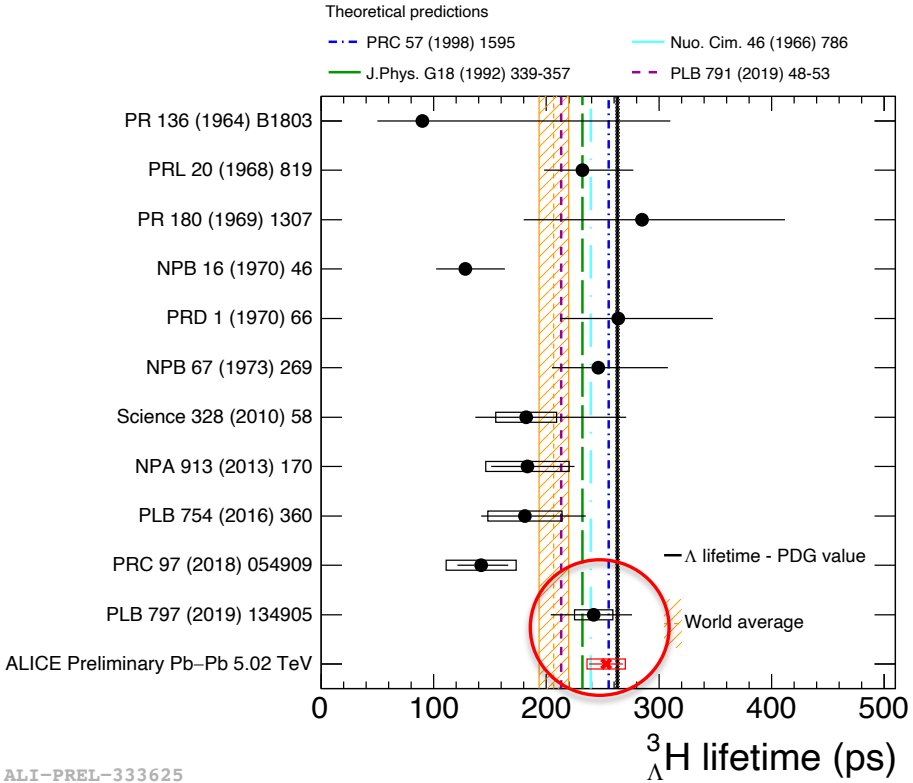
Abstract

One of the key challenges for nuclear physics today is to understand from first principles the effective interaction between hadrons with different quark content. First successes have been achieved using techniques that solve the dynamics of quarks and gluons on discrete space-time lattices[1,2]. Experimentally, the dynamics of the strong interaction have been studied by scattering hadrons off each other. Such scattering experiments are difficult or



Physics highlights: hypertriton lifetime

Hypertriton and Anti-Hypertriton measurement in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV via two-body decay
ALICE Coll., PLB 797 (2019) 134905



- Related to Y-N (and Y-N-N) forces
- **Weakly bound** ($B_{d\Lambda} \approx 130$ keV)

→ expect value close to free-Λ lifetime

- Previous experiments report **significantly smaller values**

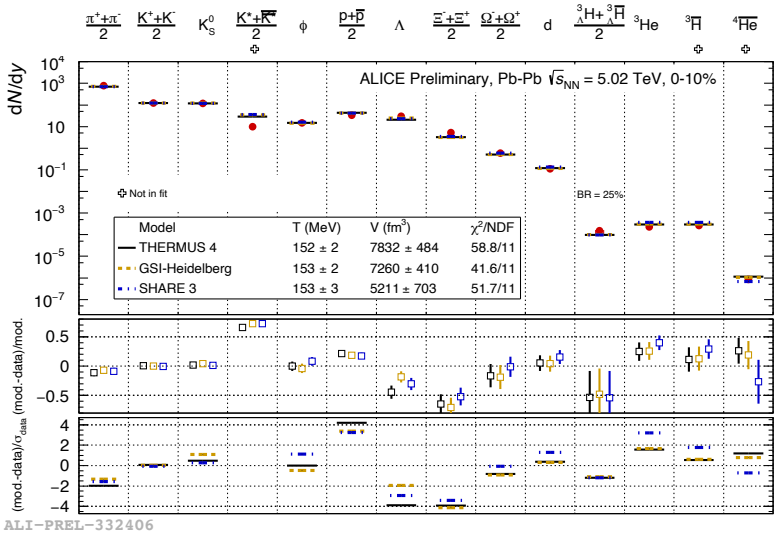
→ **Hypertriton lifetime puzzle**

- ALICE result is **consistent with world average and free-Λ lifetime**
- New ALICE preliminary result from 2018 Pb-Pb data moves **closer to free-Λ lifetime**

→ **Run 3 and 4: lifetime with 1% accuracy, branching ratio**

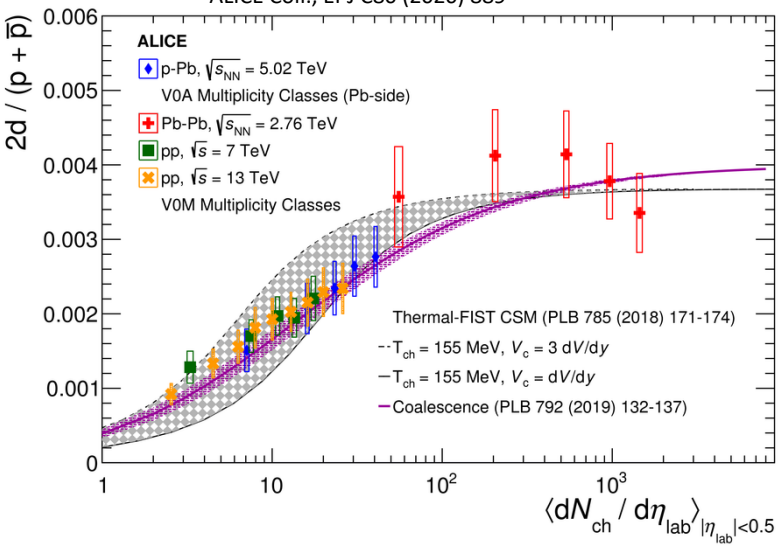
ALI-PREL-333625

Physics highlights: light- and hypernuclei production



(Anti-)deuteron production in pp collisions at √s = 13 TeV

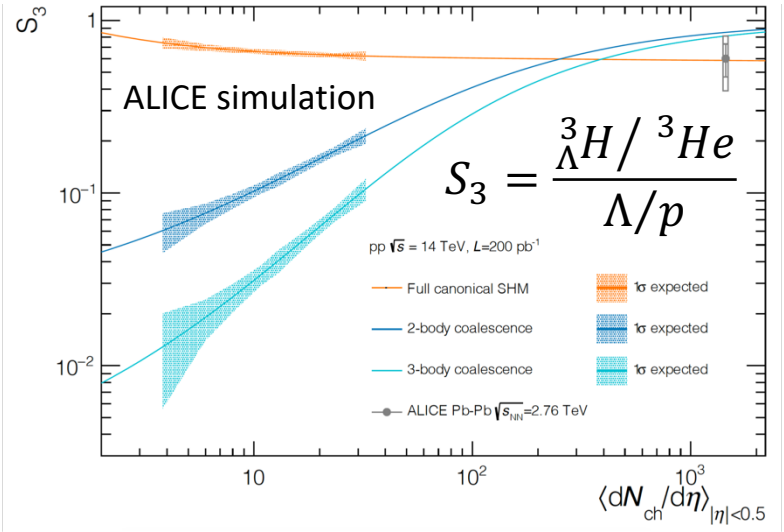
ALICE Coll., EPJ C80 (2020) 889



- Hadron yields, also **weakly bound nuclei**, well described by **statistical hadronization models**
- Production mechanism for nuclei unclear
- Final-state **coalescence** of nucleons may occur

- **Phase-space proximity and local conservation laws** matter
- Coalescence and canonical statistical hadronization models indicate **similar system-size dependence for deuteron production**

Physics highlights: light- and hypernuclei production



(Anti-)deuteron production in pp collisions at √s = 13 TeV
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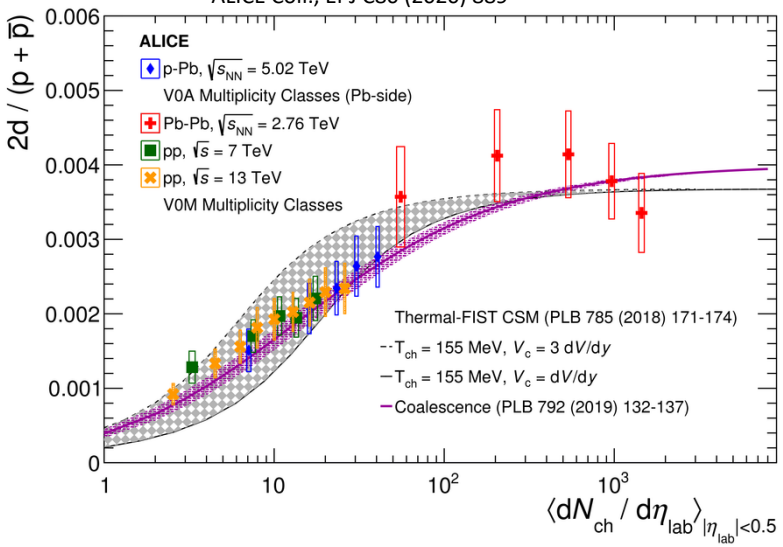


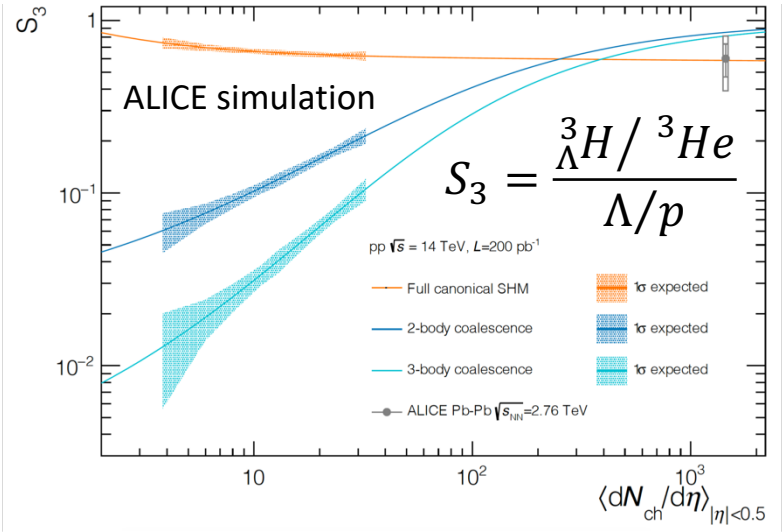
- Hypertritons are **extended objects:**

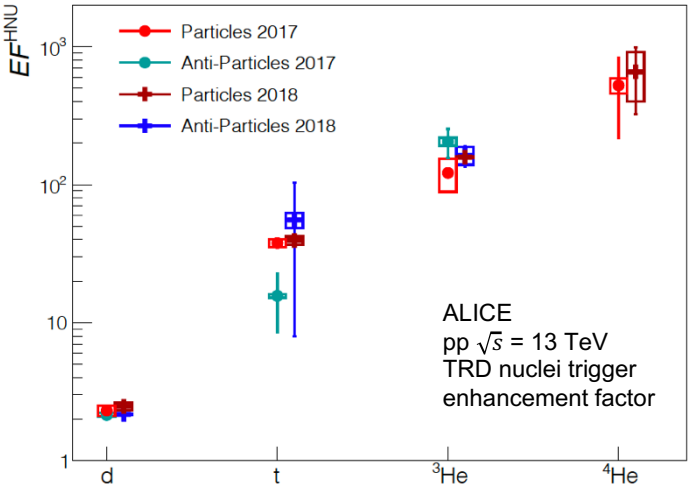
  $\langle r \rangle \approx 10.6$ fm

- Expect large sensitivity to production mechanism **in small systems (pp)**

- **Phase-space proximity and local conservation laws** matter
- Coalescence and canonical statistical hadronization models indicate **similar system-size dependence for deuteron production**

Physics highlights: light- and hypernuclei production





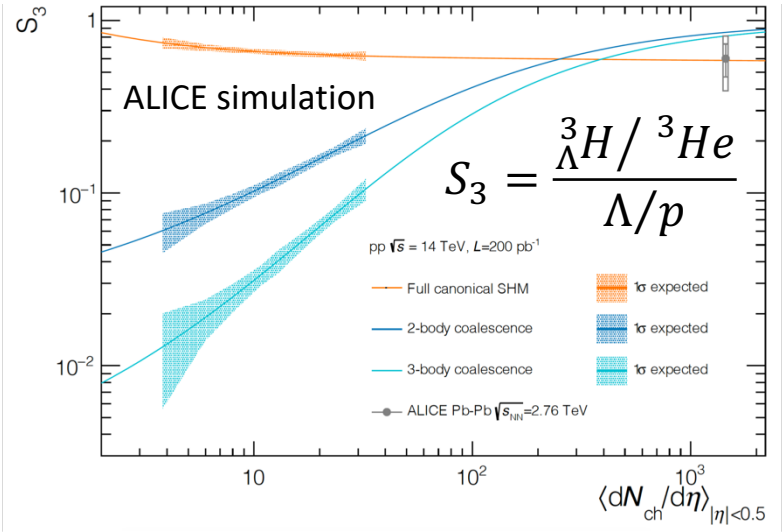
- Hypertritons are **extended objects:**

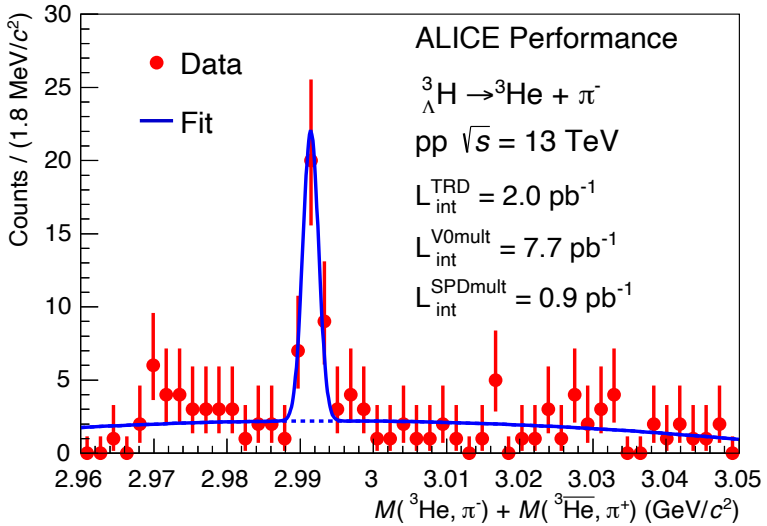
  $\langle r \rangle \approx 10.6$ fm

- Expect large sensitivity to production mechanism **in small systems (pp)**

- **TRD nuclei trigger** based on high dE/dx signal in pp collisions from 2017 and 2018

Physics highlights: light- and hypernuclei production





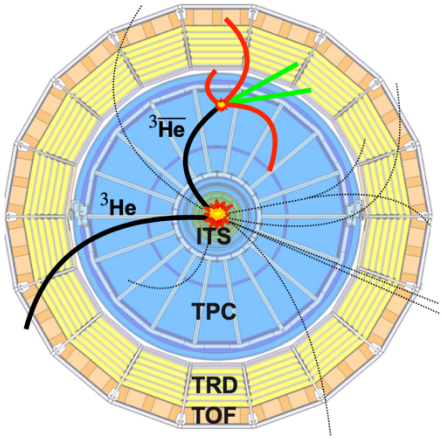
- Hypertritons are **extended objects:**

  $\langle r \rangle \approx 10.6$ fm

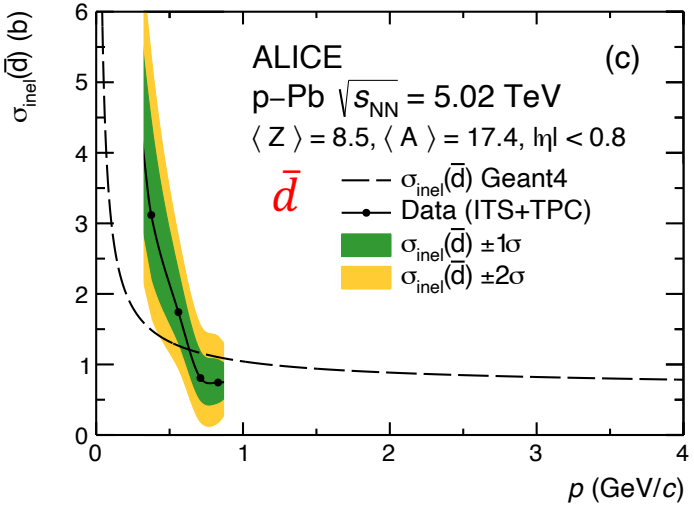
- Expect large sensitivity to production mechanism **in small systems (pp)**

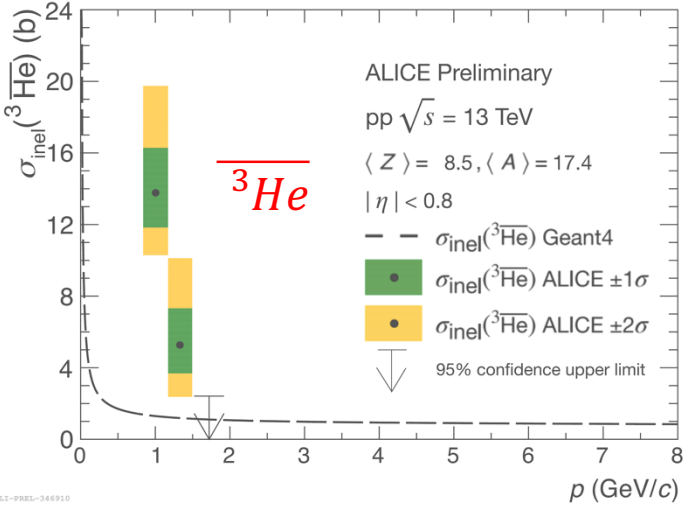
- **First observation** of hypertriton production in pp
- S_3 measurement with ~30% uncertainty in reach
- Run 3 and 4:
  - precision measurements of $^3_\Lambda H$, ^4He in pp, Pb-Pb
  - $^4_\Lambda H$, $^4_\Lambda He$, $\Lambda_c^+ nn$, …

Physics highlights: anti-nuclei absorption



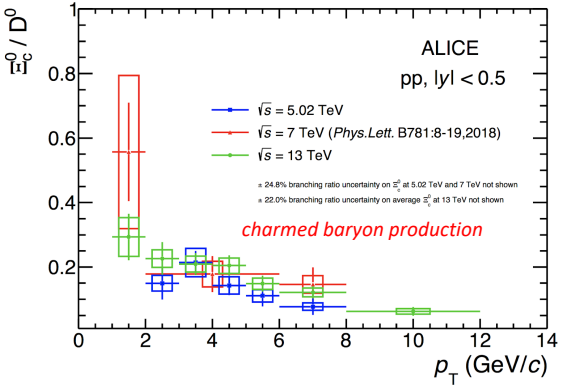
Measurement of the low-energy antideuteron inelastic cross section
ALICE Coll., PRL 125 (2020) 162001

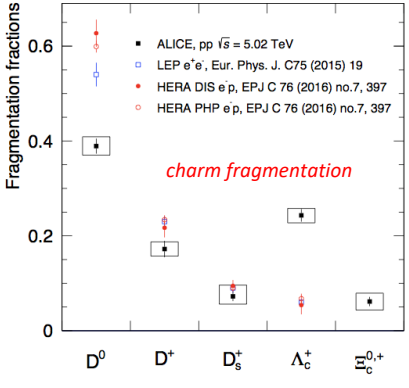


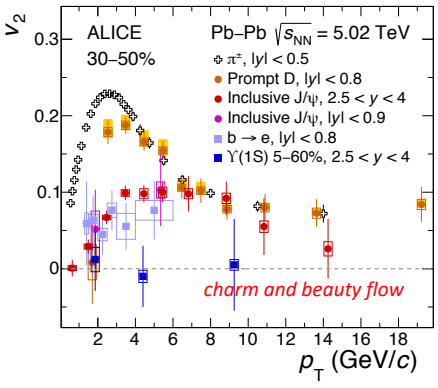


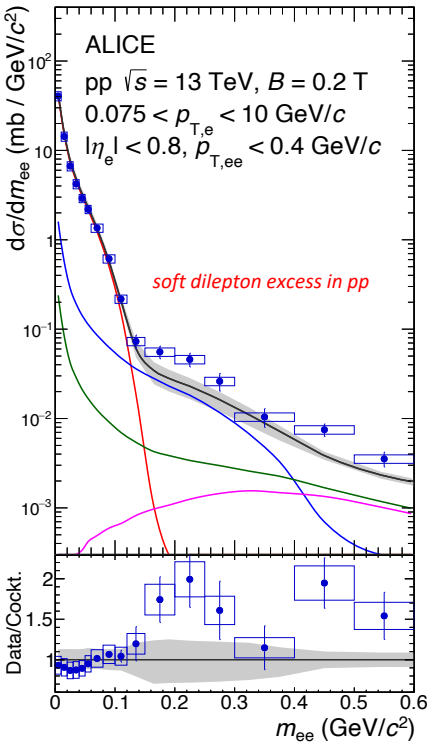
- anti-nuclei absorption cross sections are important for indirect **cosmic dark matter searches**
- so far no measurements available below 10 GeV/c
- novel approach to use the **ALICE detector material as absorber**

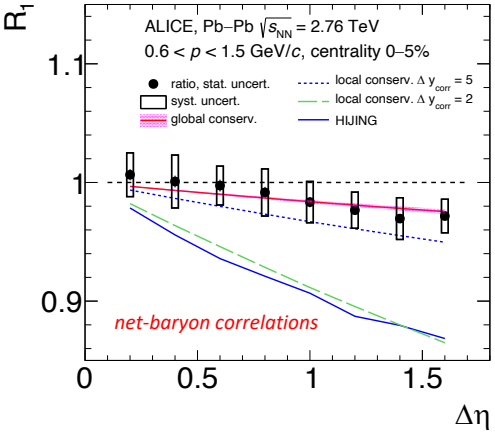
ALICE *classics*

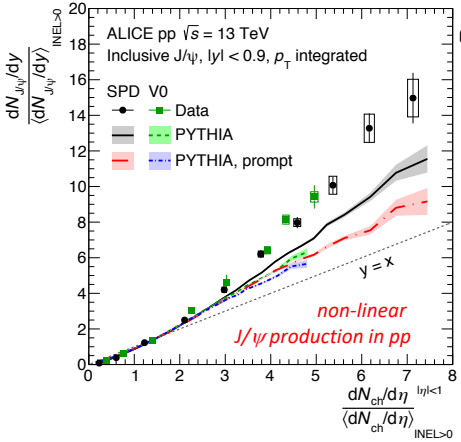


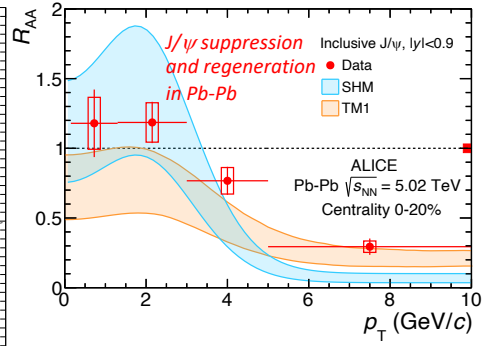












and much more...

Summary

- ALICE put forward a very ambitious upgrade program for LHC Run3 and 4
- Despite COVID-19 crisis, all projects are well on track for start of Run3 in 2022
- ALICE continues to produce high-quality physics results
- Studies and R&D towards an LoI (2021) for ALICE 3 have started